

Regeneration of Amputated Avian Bone by a Coral Skeletal Implant

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Bone fractures are common in both wild and captive birds (1, 2). Avian bones are thin and brittle and tend to break into fragments or shatter upon a variety of natural events (midair collisions, fights with other animals; ref. 2) or anthropogenic experiences (wounding by gunfire, collisions with cars or fences, encounters with traps, attacks by dogs or cats, etc.; ref. 1). The prospect of full recovery following repair of avian bone fracture is often poor, and the complication rate is high (3). For wild birds, anything less than complete normal function cannot be regarded as successful, and slight malunion or a change in a few degrees of rotation can produce a severe loss of flight function (4). Furthermore, in nomadic species, time is critical because long periods of rehabilitation may prevent the birds from reuniting with their flocks. In experiments with implantation of fragments of skeleton from the coral Stylophora pistillata, we found the implants to be avian osteo-conductive biomaterial, acting as a scaffold for a direct osteoblastic deposition. In the case study presented here, the bird regained complete flight activity within 2 weeks after surgery, with full regeneration of the amputated ulna.

The general principles for treating fractures in birds are similar to those established for mammals and include rigid stabilization (primary bone healing does not occur if there is a gap or motion at the fracture site; ref. 4). However, treatment such as external coaptation (slings, bandages, casts, splints, etc.), intramedullary pins or rods, bone plate fixation, or modifications of any of the traditional means of external skeleton fixation (3–5) not only fails for rehabilitating wild birds, but also involves prolonged hospitalization of avian patients. Internal fixation is one of the best procedures for fracture management, but the brittle nature of

avian bones (3–5) results in problems that are not encountered in mammals.

We recently investigated the use of coral skeleton as a natural intramedullary fixation device for fractures of bird bone and found that fractured avian bones can be rehabilitated following the internal implantation of coral skeletal pins (unpubl. data). This investigation was based on studies with mammals (including humans) documenting that coral skeletons may be employed as osseous substitutes, as scaffolds for direct osteoblastic application, or as an artificial bone filler for repairing bone defects (6, 7). The coral tested here was of the branching species *Stylophora pistillata*, one of the most abundant coral species in the Gulf of Eilat (8).

Mature domestic pigeons (*Columba livia domestica*) were randomly assigned to a variety of treatment groups (in preparation). For all radiographic and surgical procedures, the birds were given Halothane as a general anesthetic. The skin was prepared for aseptic surgery using a septal scrub followed by a povidone-iodine wash. Whenever possible, flight feathers were not removed or clipped; others were plucked over the intended incision. Reflexes and cardiac and respiratory activities were monitored. Birds were placed on their backs and a limited ventral approach to the ulna was performed. Two of the same bones from the wings of two birds were used as experimental and control bones (banded in the traditional manner; ref. 5). Small processed coral pins were obtained from SagivCoral, P.O. Box 3337, Ramot Hashavim 45930, Israel. Postoperative radiographs were taken to evaluate fracture repair and to document the status of the coral implant. Pigeons were housed in the flypen system and fed with a commercial pigeon food supplemented with vitamin D and oyster shell as a calcium source.

In one of the experiments, which is detailed in this communication, the proximal half of the ulna (which pro-

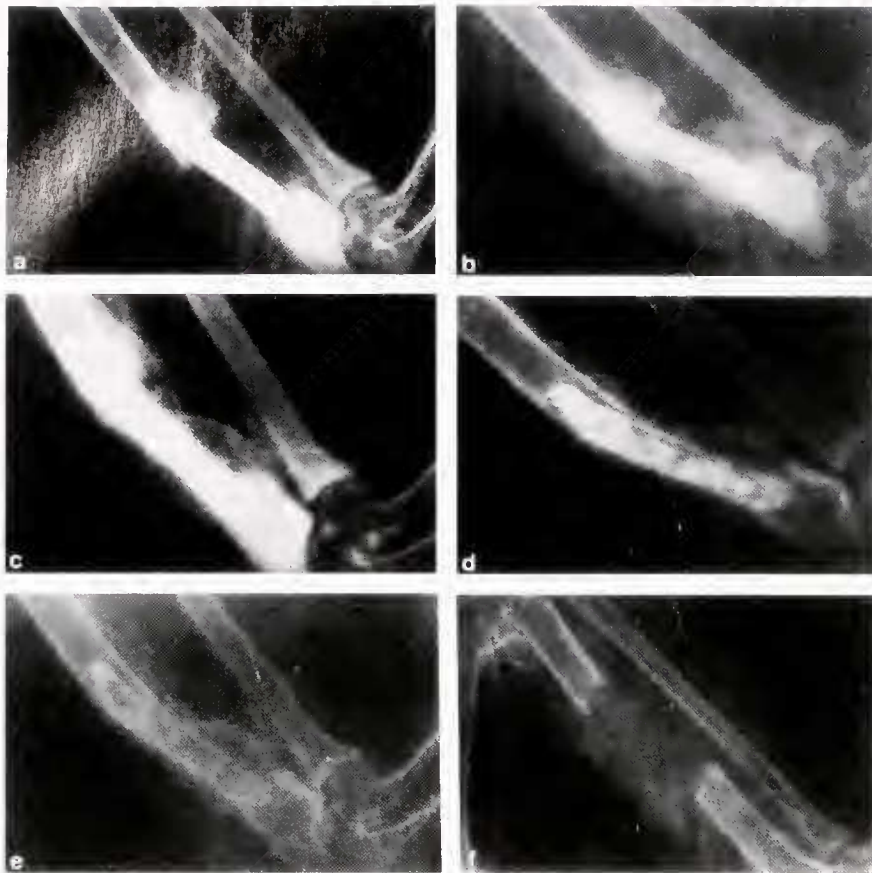


Figure 1. Progressive repair of ulna fracture treated by implantation of an intramedullary coral pin (a–e), compared to control, an untreated amputated ulna (f). Weeks after operation: a = 2, b = 4, c = 6, d = 8, e, f = 12.

vides primary support for the wing) was accidentally comminuted during surgery. Full rehabilitation of this amputation bone by the use of coral skeleton implant is described here.

In the case of the accidentally comminuted ulna, all brittle fragments were immediately removed and a small coral pin (24 mm length, 4 mm diameter) was first passed distally and then retrogradely until resistance was met at the proximal side of the ulna. The coral pin was then firmly wedged in place, forming an inert calcium carbonate milieu between the two separated parts, replacing the amputated portion of the ulna. This pigeon used the treated wing freely 14 days after the operation, alleviating ankylosis resulting from joint immobilization. In the control bird, the entire segment of proximal ulnar bone (cortex and medulla) was removed using Gilgi wire.

Two weeks after the operation, the coral pin was encapsulated firmly at both ends by overgrown calcium deposits and callus formation along the pin shaft, providing rotational stability (Fig. 1a). After 4 weeks (Fig. 1b), the coral implant was already overgrown by deposited material. By 6 weeks (Fig. 1c), deposited material surrounded the implant

in layers and the first sign of coral resorption was evident. During resorption, which was significantly advanced at 8 and 12 weeks (Fig. 1d, e), radiography showed that the area between the two ends of the broken ulna was being filled with accumulated new bone, replacing the degradable pin. *Stylophora pistillata* skeleton (although its mechanical and biological properties were not yet evaluated) was thus found to be avian osteo-conductive biomaterial, acting as a scaffold for direct osteoblastic deposition. The bird regained full flight activities 2 weeks after surgery, and the coral pin activated skeletal regeneration (compare with the control; Fig. 1f). This process ended in complete regeneration of the amputated area.

This case of regeneration of an amputated bone and our study (in prep.) demonstrate the value of coral skeletal implants for avian bone repair. Coral material (calcium carbonate) is well tolerated by bird tissue. The pin matrix is porous enough to be colonized by the birds' bony cells, is biodegradable, and is easily adjustable in size and shape to the osseous site of grafting. Previous studies employing coral implants for bone repair in mammals have shown that coral resorption rates varied with porosity of the coral

species used and with host reaction (9). We used natural fragments of *S. pistillata* skeletons, the first pocilloporid coral used in vertebrate skeleton rehabilitation. Each year, around the globe, veterinarians tend an ever-increasing number of wild and domestic birds with broken bones; unfortunately, at present the prognosis for many of these birds is poor. The approach described here may provide a fast and dependable method for rehabilitation of avian fractures, increasing the survival rate of birds treated for bone injuries.

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